# INFLUENCES OF FIRE AND SODIUM-CALCIUM BORATE ON CHAPARRAL VEGETATION

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Fire is commonly recognized as an important factor in the determination of the composition of the extensive chaparral areas of California. Environmental conditions, physiognomy of the vegetation, and physiological responses of the individual components have led many authors to conclude that the chaparral is a firetype vegetation, the composition of which is perpetuated through the action of fire. Cooper (1922), Sampson (1944), Horton and Kraebel (1955), Patric and Hanes (1964) and Sweeney (1956) have made detailed ecological studies of chaparral areas of various parts of California. The literature on vegetation and fire has been reviewed by the above authors and by Ahlgren and Ahlgren (1960).

Seeds may germinate readily or require various conditions to break dormancy caused by embroyo or seed coat conditions. Amen (1963) asserts that seed germination, germination mechanics, and the adaptive significance of the dormant state have not been adequately investigated. Quick (1935), Stone and Juhren (1951), Sweeney (1956), and Hadley (1961) have investigated the germination mechanics of some species which appear following chaparral fire. Sweeney (1956) found that both scarification and experimental burning of excelsior above planted seeds of "burn" species increased germination. Hadley (1961) increased germination of *Ceanothus megacarpus* both by scarification and by heating the seeds to 100° C for five minutes.

In recent years, chemicals such as sodium-calcium borate, bentonite clay, and diammonium phosphate have found increasing use as fire retardant chemicals. Experiments have shown that borate compounds inhibit germination and are toxic to mature plants when used in high concentrations (Brenchley, 1914; Crafts, 1956; Johansen, 1958). Field investigation of the effects of sodium-calcium borate on chaparral vegetation has not been reported.

The purpose of this investigation is mainly to record the nature of vegetation which appears following fire in a chamise chaparral area. Consideration is also given to germination responses of some of the herbaceous species which appeared on the burned area immediately following the fire and to the effect of sodium-calcium borate on growth in an affected area.

The study area is located in the southern Sierra Nevada foothills within Sequoia National Park. The study plots are in the lower Elk Creek drainage at an elevation of approximately 2100 feet. Soil is of the Vista

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series (Storie and Weir, 1962), and ranges from two to five feet in depth. Weather and fire fighting data were taken from National Park Service records at the nearby Ash Mountain headquarters. The Tunnel Rock fire began June 25, 1960 and burned 4673 acres of chaparral and woodland on the south and east slopes of Ash Peaks. It was estimated that 25 to 30 500 gallon drops of sodium-calcium borate were made before the fire was brought under control.

Seventeen field plots, each four meters square, were located in the lower edge of the burned chaparral. Eleven of these plots are on the south-facing slopes which predominate in the burned area. Five plots are in the burned area, three on the margin of the borated and burned area, and three in the borated and burned area. The three control plots are in one of the few limited areas of unburned chaparral. All plots lie within a radius of 300 yards.

Ring counts were made of specimens of the woody perennial *Adenostoma fasciculatum* which had burned near the study plots. The number of annual rings in three complete sections varied from 45 to 51. The center of some sections was rotten or hollow, but 30 to 48 annual rings were visible even in the six incomplete specimens. Because aerial portions of this plant are killed by the heat of chaparral fire, it is assumed that there had not been a major fire in the immediate area for at least 50 years.

Principal observations and studies of the vegetation were made during the first growing season following the fire, the spring of 1961. Plant collections were made to determine the floristic composition of the area, and to find the frequency of occurrence of these plants on burned and adjacent unburned areas. The collections included 148 species, of which 118 were herbaceous, 25 annuals, 20 perennials, and seedlings of three woody perennials were found on the burned chaparral areas. Those species occurring on the study plots are listed in Table 1. More detailed information regarding distribution of vegetation in all areas may be found in Stocking (1962).

Marked differences in occurrence and abundance of certain species was evident when the burned area and the unburned control areas were compared. The chaparral cover of unburned south-facing slopes is predominately *Adenostoma fasciculatum, Ceanothus cuneatus, Arctostaphylos viscida, Fraxinus dipetala,* and *Quercus wislizenii* occur near margins of the dense chaparral and on the more mesic north-facing slopes. No seedlings of woody perennials were encountered either under the unburned brush or in openings in the brush. Only 12 herbaceous species were found in the control area. Failure of seedling establishment in these areas may be due to any of many factors including limited temperature range, root distribution, low light intensity, presence of inhibitors, and necessity of heat of fire for germination.

Seedlings of *Eriodictyon californicum* and *Ceanothus cuneatus* were occasionally encountered, particularly on the north-facing slopes (table

1). On burned chaparral areas, seedlings of chamise were abundant: 372 seedlings appeared on one 4 m study plot. Only three of these seedlings survived the hot dry summer. Survival of these seedlings varied on the different plots, but was low in all cases. Low survival of chamise is thought to be due to the shallow nature of the root system during the first year of growth.

Presence of herbaceous vegetation in open areas indicates that light intensity may play an important part in the establishment of some species in unburned chaparral areas. Species found most often in open areas in the brush of control plots are shown in Table 1. Of these species only *Lotus scoparius, Daucus pusillus,* and *Gastridium ventricosum* were found on adjacent burned areas. Occurrence of these species in unburned brush areas indicates that conditions caused by fire are not requisite for their germination and growth. If invasion from unburned chaparral areas is to account for vegetation on the adjacent burned areas it would be expected that these species would predominate. Of the species which occurred on the burned area only the above mentioned species could have originated in neighboring unburned areas. The bulbous perennials, *Brodiaea lutea* var. *scabra,* and *Chloragalum pomeridianum* developed from underground bulbs on both burned and unburned areas. The other species of abundance on the burn were not present in the control area.

All of the scattered individuals of *Quercus wislizenii* and *Fraxinus dipetala* were in mesic locations, and all crown sprouted following the fire. Less than one-half of the burned chamise sprouted from their conspicuous basal burls. Most of these crown sprouts survived the first hot summer following the fire. No seedlings of any species were noted immediately adjacent to the bases of mature chamise. Lack of herbaceous vegetation near chamise may be due to the action of phytoxic agent found in the leaves of the species by Naveh (1960). Herbaceous plants were present only where open areas existed in the otherwise dense cover of the control plots. The thinning out of the cover appared to be due both to the advanced age of the stand and to the long period of low rainfall.

Observations were made of: 1, grassy areas surrounded by chaparral; 2, disturbed areas formed by an improved trail; and 3, disturbed areas formed by a road and utility right of way. The herbaceous flora of these burned areas differed from that of burned chaparral areas. With the exception of *D. pusillus,* and *Gastridium ventricosum,* no species occurred on the burned chaparral area which also occurred on the disturbed areas. Presence of these species on the above mentioned areas may be due to many factors. It is possible that no mature plants, and therefore no seeds, existed on chaparral areas prior to the fire. It is also possible that the seeds of these species have low heat tolerance, and could survive fire only in open areas where the heat would not be so intense. The relation of heat generated by chaparral fire to seed survival and germination has been discussed by Sweeney (1956).

Table 1. Species and Number of Individuals on 4 by 4 Meter Plots. March–May, 1961

| SPECIES | Plots on South-Facing Slopes: Control Plots, Unburned 1 | 2 | 3 | Adjacent To Control 1 | 2 | 3 | 4 | 5, Burned | Borate Plots, Burned | | | Adjacent To Borate, Burned | | | Plots on North Facing Slope, Burned | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ranunculus*[1] *herbecarpus* | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | — | — | 5 | 2 |
| *Malacothamnus fremontii* (S) | — | — | — | 5 | 1 | 16 | 21 | 120 | — | — | — | 1 | 1 | — | 2 | 1 | — | 6 | 2 | — |
| *Dicentra chrysantha* | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — | 33 | 18 | 3 | 5 | 53 | 21 |
| *Cerastium viscosum* | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 | — | — | — | 4 | 3 |
| *Montia perfoliata* | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 | — | — | — | 4 | — |
| *Linanthus ciliatus* | 27 | 278 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| *Emmenanthe penduliflora* | — | — | — | 1 | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| *Eriodictyon californicum* (S) | — | — | — | — | — | — | — | 1 | — | — | — | 1 | 5 | — | 9 | — | 4 | 8 | 4 | 2 |
| *Cryptantha micromeres* | — | — | — | — | 53 | 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 |
| *Crypantha muricata* | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 | 2 | — | — | 2 | — |
| *Scutellaria tuberosa* | — | — | — | — | — | — | 1 | — | — | — | — | — | — | — | — | 1 | — | 13 | 2 | — |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lithophragma heterophylla* | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 4 | — | — | 2 | 3 | — |
| *Tillea erecta* | — | 337 | — | 24 | — | — | — | 3 | — | — | — | — | — | — | — | — | — | — | — | — |
| *Adenostoma fasciculatum* (S) | — | — | — | 310 | 372 | 279 | 175 | 79 | — | — | — | 123 | 99 | 103 | 320 | 174 | 12 | 188 | 87 | 40 |
| *Trifolium ciliolatum* | — | — | — | — | — | 2 | 3 | 2 | — | — | — | — | — | — | 1 | — | 4 | — | 1 | — |
| *Trifolium microcephalum* | — | — | — | 65 | 57 | 174 | 210 | 62 | — | — | — | — | — | — | 3 | 6 | 67 | — | 39 | — |
| *Lotus subpinatus* and *micranthus* | — | — | — | 350 | 148 | 312 | 120 | 79 | — | — | — | — | — | — | 16 | 22 | 41 | — | 43 | — |
| *Lotus scoparius* | — | 250 | 3 | 202 | 407 | 372 | 28 | 21 | — | — | — | 3 | 17 | — | — | — | — | — | — | 13 |
| *Astragalus congdonii* | — | — | — | 232 | 141 | 421 | 574 | 372 | — | — | — | 122 | 72 | 239 | 61 | 126 | 36 | — | 72 | 59 |
| *Astragalus didymocarpus* | — | — | — | — | — | 61 | 42 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| *Ceanothus cuneatus* (S) | — | — | — | — | — | — | — | — | — | — | — | 1 | 1 | 2 | 17 | 5 | 10 | 30 | 20 | 11 |
| *Sanicula crassicaulis* | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | — | 18 | — |
| *Daucus pusillus* | — | 183 | 20 | 1 | — | 12 | — | 1 | — | — | — | — | — | — | 1 | — | — | — | — | — |
| *Galium parisiense* | 145 | 373 | 177 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| *Galium spurium* | — | — | — | 6 | 1 | — | 2 | — | — | — | — | — | — | — | 1 | 1 | 1 | — | — | — |
| *Filago californica* | 42 | 342 | 87 | 7 | 27 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| *Evax acaulis* | — | 269 | 13 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |

TABLE 1 (continued)

| SPECIES | Plots on South-Facing Slopes | | | | | | | | | | | | | | Plots on North Facing Slope | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control Plots | | | Adjacent To Control | | | | | Borate Plots | | | Adjacent To Borate | | | | | | | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 | | | | | | | | | | | | |
| | Unburned | | | Burned | | | | | | | | | | | Burned | | | | | |
| *Chloragalum pomeridianum* | 2 | 2 | 10 | — | — | — | 3 | 3 | 58 | 287 | 415 | 79 | 49 | 103 | 12 | 7 | 4 | 3 | 11 | 4 |
| *Brodiaea lutea* var. *scabra* | 235 | 280 | 28 | 1560 | 241 | 470 | 908 | 174 | — | — | — | — | — | — | 24 | 340 | — | 153 | 34 | 90 |
| *Brodiaea volubilis* | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 113 | 34 | — | — | 115 | — |
| *Bromus madritensis* | 17 | 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| *Festuca octoflora* | — | — | — | — | 6 | 4 | 1 | — | — | — | — | 1 | 4 | 1 | — | — | 1 | — | 9 | 3 |
| *Festuca megalura* | 80 | 42 | 478 | 11 | — | 5 | 2 | 2 | — | — | — | 3 | — | 6 | 1 | 8 | — | 4 | 5 | — |
| *Melica californica* | — | — | — | 1 | — | — | — | — | — | — | — | — | — | — | 1 | — | — | 1 | 1 | — |
| *Gastridium ventricosum* | — | 25 | — | 10 | 2 | 47 | 6 | 26 | — | — | — | 7 | 3 | 37 | 3 | 5 | — | 10 | 2 | 2 |

(S) indicates seedling of woody perennial. Plants which occurred only once were omitted. They were: *Dendromecon rigida, Clarkia unguiculata, Marah horridus, Stipa lepida,* and *Poa scabrella.*

[1] Nomenclature in this paper follows that of Munz (1959).

In addition to collections made in burned chaparral areas, many species were found in woodland and riparian areas burned in the same fire. No species were found in these areas which occurred in abundance on the chaparral area. This eliminated the likelihood of invasion from these areas during the first season following the fire.

*Dendromecon rigida* and *Emmenanthe penduliflora* were found in great abundance on localized areas of burned chaparral. These species were not found on unburned areas but have been located on other disturbed chaparral areas. They did not occur on the study plots. The most abundant herbaceous plant which appeared on burned chaparral areas was the perennial, *Astragalus congdonii. Malacothamnus fremontii* was locally abundant but only scattered in the area of the study plots. Both these plants are very rare in unburned chaparral areas. Only a few plants have been located by the author in disturbed areas of unburned chaparral in the southern Sierra Nevada.

Other seedlings found in abundance on burned chaparral areas, but rarely elsewhere, were *Crypantha micromeres, Trifolium ciliolatum, T. microcephalum. Lotus subpinnatus, L. micranthus,* and *Astragalus didymocarpus*. Distribution patterns of species restricted to the burn varied suggesting differences in abundance of these plants prior to the fire. *Emmenanthe penduliflora* was most common in rocky areas following the fire. This suggested that there were focal areas in which a few plants occurred in the interval between fires. Horton (1960) postulated similar origins of firetype plants in southern California.

*Ceanothus cuneatus* was nowhere abundant prior to fire, but seedlings appeared following fire on north-facing slopes (table 1). This finding concurs with those of Horton (1945), Hadley (1961), and Patric and Hanes (1964) who found that in areas unburned for over 50 years, *Ceanothus* spp. were replaced by species with a longer life span. Horton and Kraebel (1955) found that the seeds of *Ceanothus* spp. were stimulated to germinate through the action of fire. Although chamise seedlings were not found on the control areas they were abundant on the burned areas. Stone and Juhren (1953) found that chamise produced seeds with different germination responses at different times in their lives. They believed that an old stand of brush would contain a large number of viable seeds which would germinate in response to fire.

One possible explanation for the widespread abundance of *Astragalus congdonii, Trifolium ciliolatum,* and some other species on burned areas but not elsewhere is long term seed survival. It is possible that an abundance of seeds of these species had survived in the soil since a period of abundance following the last fire. These two species were found to have two types of seed, one which germinated readily and another more abundant type which required scarification for germination (table 2). The readily germinable seed would make possible scattered occurrence in the absence of fire. The other seed type would remain in the soil in the period between fires. Both species are legumes, a group which is known to contain many species with long lived seeds (Quick, 1961). This condition could explain the widespread occurrence of these two plants following fire. *Emmenanthe penduliflora* and *Malacothamnus fremontii* were found to have seeds which would germinate only when scarified (table 2). It is postulated that these species occur in the absence of fire only where disturbances would break the seed coat of an occasional seed. This would explain their local abundance following fire. Amen (1963) states that the mechanisms of such dormancy are elusive, but that delayed germination represents a special adaptation which favors the continued propagation and survival of the species.

Burned north-facing slopes had a somewhat different cover of both annuals and perennials than did the plots on the drier south-facing slopes (table 1). In these areas vegetative activity was observed to begin earlier and reproductive activity to end later than on the south-facing slopes. Seedling survival of perennial species was also greater.

Observations made during the second spring following the fire indicated that the vegetational composition had changed. Annual species which were unique to the burned area during the first season had, for the most part, disappeared. Only a few individuals of *Emmenanthe penduliflora* were found at this time. The transient occurrence of such species suggests a direct relationship between fire and germination. Perennial species such as *Astragalus congdonii* and *Brodiaea lutea* var. *scabra* remained in abundance on the burned areas during the second season.

In the course of field investigations during the first growing season it was found that a section of the study area lacked the annual and perennial vegetation characteristics of other burned areas. It was learned that this area was one of 25 to 30 locations hit by aerial drops of the fire retardant chemical, sodium-calcium borate.

Complete lack of perennial and herbaceous seedlings in this area indicated that boron was present in highly toxic concentrations in the surface layers of the soil. At a depth of 0 to 7.6 cm, any toxic materials would be in contact with young absorbing roots. The one herbaceous perennial present, *Chloragalum pomeridianum,* showed typical boron toxicity symptoms of leaf burn and marginal chlorosis. These symptoms in *Chlorogalum pomeridianum* suggested that boron was also present in the root zone of this plant, 7.6 to 30.5 cm beneath the surface. No conditions attributable to boron were exhibited by crown sprouts of chamise which has a deeper and more extensive root system than do the herbaceous species.

Vegetation of plots adjacent to the above mentioned area was more sparse than on neighboring unaffected areas. The species here were the same as on areas not affected by "borate." Sparcity of vegetation in this area suggested that boron was present in relatively low concentrations. The species present of the affected areas are shown in Table 1.

Colorimetric determination of boron in soil collected from the affected area was done according to the quantitative method of Hatcher and

Table 2. Effect of Mechanical Rupturing of Seed Coat on Germination of Some Burn Species Including Two with Seed Coat Dimorphism

| Sepcies | Percentage germination[1] Not Scarified | Scarified |
|---|---|---|
| *Malacothamnus fremontii* | 0 | 30 |
| *Emmenanthe penduliflora* | 0 | 41 |
| *Trifolium ciliolatum* (buff seed color) | 65 | — |
| *Trifolium ciliolatum* (mottled seed color) | 0 | 82 |
| *Astragalus congdonii* (buff seed color) | 74 | — |
| *Astragalus congdonii* (mottled seed color) | 0 | 78 |

[1] Each treatment consisted of three replications using 25 seeds per dish. Germination was defined as emergence of the radicle by the end of 30 days.

Wilcox (1950). Analysis was made to determine the residual water soluble boron in the soil following aerial application. The manufacturer stated that concentrations of two to five ppm of boron in soil is toxic to most plants (U.S. Borax and Chemical Corp., 1957).

Boron is slowly removed from soil both by leaching and fixation. Crafts (1956) stated that a pattern of concentrated rainfall is much more effective in leaching soil sterilants of this type than is a comparable amount of intermittent rainfall. During the first winter following the application of "borate," rainfall was intermittent in occurrence and in small quantities. 5.66 cm of rain fell between the application and the collection of the first soil samples. Progressive leaching of the soil by low, intermittent rainfall is presumed to have reduced the boron concentration present immediately following application. At the end of the growing season, boron remaining in the top 7.6 cm of the soil in the affected area was reduced to 25 to 30 ppm. Fifteen ppm boron were found at depths of both 7.6 to 20.3 cm and 20.3 to 30.5 cm. All these concentrations are well above the minimum toxic concentrations. It is assumed that a somewhat higher boron concentration was present during the period of seed germination.

Analysis of soil collected in the same area during the second spring following the fire showed that 6.5 ppm of boron remained in the top 7.6 cm. This concentration remained after a total rainfall of 101 cm. It was again observed that no seedlings occurred in the area and that *Chlorogalum pomeridianum* continued to exhibit toxicity symptoms. Vegetation of the plots near the margin of the "borate" drop was much more abundant than during the first year. Vigorous chamise crown sprouts evidenced no toxicity in any areas.

These data indicate that concentrations of boron between 30 ppm and 6.5 ppm made seedling development impossible. Soil in this area remained sterlie for twenty months after the aerial application of "borate." At least 23.5 ppm of boron was removed by leaching or become unavailable by absorption during the second year following application. It is likely that 6.5 ppm of boron remained at the onset of the third winter (1962–1963). Rainfall during the winter of 1962–1963 was 75.11 cm.

Most seeds, both with or without seed coat dormancy, would germinate within the first two seasons following fire. Once these seeds began to germinate they would be exposed to the toxic concentrations of "borate." Not until the third growing season following fire did *Lactuca serriola,* a species with wind borne seeds, and a few grasses begin to appear at the margin of the area directly affected by the aerial drop. This would indicate that the rate of depletion continued during the third year, and that boron was reduced to below toxic levels.

Observations made during the springs of 1963 through 1965 showed that species appearing on the area which had been affected by "borate" were not the same as those which appeared on the surrounding unaffected chaparral area immediately following fire. Species found on the "borated" areas were predominately those of neighboring disturbed areas. Further study of such areas may lead to a better understanding of the comparative roles of invasion and seed survival in the establishment of plants on burned chaparral areas.

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# THE TAXONOMIC STATUS OF STEMMATELLA (COMPOSITAE-HELIANTHEAE)

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The genus *Stemmatella* was first proposed by Weddell (Bull. Soc. Bot. Fr. 12:82. 1865) in a list of plants collected in Bolivia by M. G. Mandon and identified by Schultz-Bipontinus. Specifically, the name *Stemmatella congesta* Wedd. preceded by the collector's No. *293,* was listed without description or comment. As such *Stemmatella* was a *nomen nudum* until subsequently published by Hoffmann (1894) in his treatment of the Compositae. Bentham (1873), however, drew up a rather complete generic description, although he neglected to mention *S. congesta,* or any other species name, nor did he make reference to a specimen, but presumably he had access to one of the Mandon collections (see below).

I became interested in the taxonomy of *Stemmatella* while attempting to identify epappose forms of *Galinsoga parviflora* (Turner *et al.,* 1962; Turner and King, 1964), for such specimens, by Hoffmann's treatment would key to *Stemmatella* instead of *Galinsoga;* indeed, collections filed under the two generic names were almost identical, in spite of the fact that they were placed by both Bentham and Hoffmann in the subtribes Verbesininae and Galinsoginae respectively.

Bentham had a single sheet with 2 attached specimens of the *Mandon 293* collection at his disposal (K). One of the specimens contains heads with epappose achenes; the other has heads with epappose ray achenes *but* the disk achenes possess a well-developed pappus. One must assume